A STUDY ON MECHANICAL BEHAVIOR OF BAMBOO FIBER BASED POLYMER COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY
IN
MECHANICAL ENGINEERING

BY

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CERTIFICATE

This is to certify that the thesis entitled "**A Study on Mechanical Behaviour of Bamboo Fiber Based Polymer Composites"** submitted by **Subhash Kumar Gupta (Roll: 110ME0527)** in partial fulfillment of the requirements for the award of ***Bachelor of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

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ABSTRACT

The modern dynamic world can't imagine its development without bringing the concept of advancement in material composite. Various researches are going on in this field to achieve the desired standard. Natural fiber reinforced polymer composite has a huge affinity to replace the composite made up of synthetic fiber. This is primarily because of the advantages like light weight, non-toxic, non-abrasive, easy availability, low cost, and biodegradable properties. The synthetic fibers have higher end of mechanical properties like tensile strength and tensile modulus however the specific mechanical properties like specific tensile modulus and other specific properties (properties/specific gravity) of natural fiber gives a satisfying result for composites as compared to synthetic fiber based composites. The objective of the present study is to investigate the mechanical behaviour of short bamboo fiber reinforced epoxy based composites. Bamboo fibers with different length and contents are reinforced in epoxy resin to fabricate composite materials. The effect of fiber length and content on the mechanical behaviour of composites is studied.

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CHAPTER 1
INTRODUCTION

1.1 Background

Composite material can be defined as the material which is composed of two or more distinct material on macro scale with different properties to form a new material with a property that is entirely different from the individual constituents. The primary phase of a composite material is called a matrix having a continuous character. In other words, matrix is a material which acts as a binder and holds the fibers in the desired position thereby transferring the external load to reinforcement. These matrixes are considered to be less hard and more ductile. The composite material consists of a matrix along with a fiber with some filler material. The reinforced material can be either synthetic or natural fibers. In the demand of increasing environmental security, several natural fibers reinforced polymer composites (NFPCs) are brought into the competitive market. NFPCs provide a wide range of advantages over synthetic fiber based composites. These advantages include high strength to weight ratio, high strength at elevated temperatures, high creep resistances and high toughness [1]. These advantages can also be in the form of their light weight, high durability and design flexibility. In NFPCs, the used matrices are either thermoset or thermoplastic. Polyester, Epoxy and phenolic resin are the commonly used thermoset matrix whereas polypropylenes, polyethylene and elastomers occupy the large scale position in thermoplastic matrix.

Based on the matrix used, composite material can be divided into three types i.e. Metal Matrix Composite (MMC), Polymer Matrix Composite (PMC) and Ceramic Matrix Composite (CMC). The selection of any of the above composite material depends upon the type of application. The most commonly used composites are polymer matrix composite.

This is primarily because of their light weight and specific properties compared to ceramics and metals. Besides, the polymer matrix composites can be processed at low temperature and pressure.

In the present study, epoxy is as the matrix material. Generally, epoxy has a glassy appearance with classic advantages like good adhesion to other materials, good mechanical properties, good electrical insulating properties, good environmental and chemical resistances etc [1]. The epoxy when treated with natural fiber to synthesize a fiber reinforced polymer composite, there is an interface formed between the matrix and the fiber. The adhesion between the fibers and the matrix around this interface decides the properties of the composites based on which its further application is decided. There are numerous fibers provided by nature to the human mankind. Based on the source of origin, this natural fiber can be classified into three categories such as animal fiber, vegetable fiber and mineral fibers. The detailed classification of natural fibers is done below in the Figure 1.1.

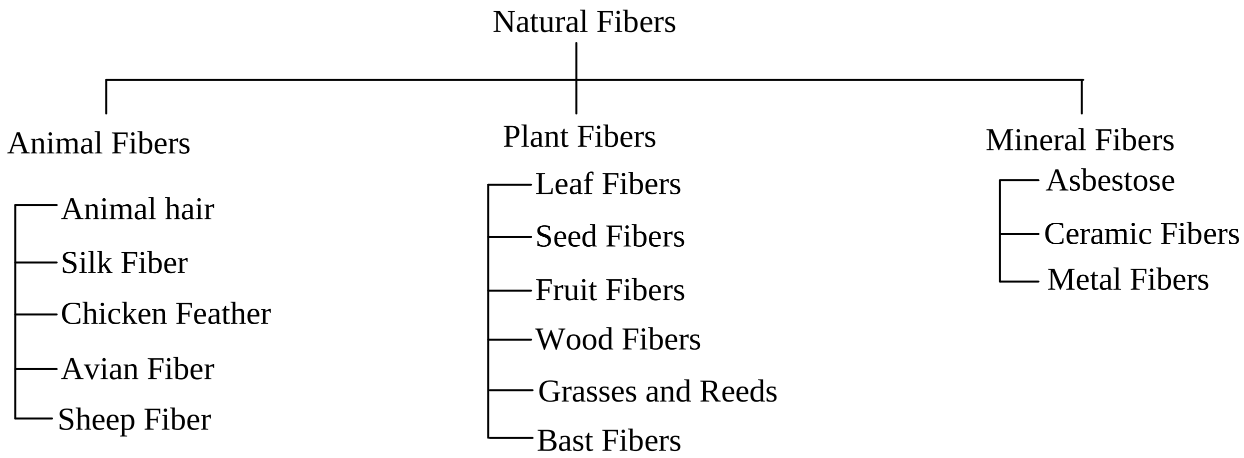

Figure 1.1 Classification of natural fibers based on source of origin

Synthetic fibers reinforced polymer composites (SFPCs) have excellent properties over NFPCs. Mechanical properties of SFPCs such as tensile strength, flexural strength, impact energy and tensile modulus have higher end value. But when the comparison is made in terms of specific properties (property/specific gravity), because of lower densities of natural fibers, NFPCs have comparable specific properties to that of SFPCs [2]. Properties of few natural fibers are presented in Table 1.1.

Table 1.1 Properties of Natural fibers [3]

Fiber	Tensile Strength (MPa)	Young's Modulus (Gpa)	Elongation at break (%)	Density gm/cc
Abacca	400	12	3-10	1.5
Alfa	350	22	5-8	0.89
Bagasse	290	17	--	1.25
Bamboo	140-230	11-17	--	0.6-1.1
Banana	500	12	5.9	1.35
Coir	175	4-6	30	1.2
Cotton	287-597	5.5-12.6	7-8	1.5-1.6
Curaua	500-1150	11.8	3.7-4.3	1.4
Date palm	97-196	2.5-5.4	2-4.5	1-1.2
Flax	345-1035	27.6	2.7-3.2	1.5
Hemp	690	70	1.6	1.48
Henequen	500 ± 70	13.2 ± 3.1	4.8 ± 1.1	1.2
Isora	500-600	--	5-6	1.2-1.3
Jute	393-773	26.5	1.5-1.8	1.3
Kenaf	930	53	1.6	--
Nettle	650	38	1.7	--
Oil Palm	248	3.2	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.9-7.8	1.4
Pineapple	400-627	1.44	14.5	0.8-1.6
Ramie	560	24.5	2.5	1.5
Sisal	511-635	9.4-22	2-2.5	1.5
E-glass	3400	72	--	2.5

Investigations on plastics and cements when reinforced with natural fibers such as banana, bamboo, coir, jute, pineapple leaf, sisal, sun hemp, straw and wood fibers have been reported [4-11]. The natural fiber used in the present study is short bamboo fiber due to many reasons. Bamboos are the largest members of the grass family. It is a long fleshy plant which technically comes under grass family but the appearance is never like grass. It is soft towards the centre and hard towards its periphery. Bamboo is mostly grown in tropical countries and is naturally occurring composites. Bamboos are largely used for the purpose like housing, forestry, agro-forestry, agricultural activities, utensils and weapons. It is mainly planted in Asian countries and constitutes about 65% of the total bamboo resources found in the world [12]. India and China is the leading nation in production of bamboo. Globally, the area occupied by bamboo is expected to be 36 million hectares or an average of 3.2 percent of the total forest area if bamboo outside forest area is included. Out of these 36 million hectares, 24 million hectares of bamboo forest, constituting about 4.4 percent of the total forest area are occupied in Asia itself [12].

Bamboo shows the mechanical properties which are analogous to that of wood. Bamboo shows better mechanical properties as compared to fibers such as sisal, banana, vakka etc. Bamboo can be used in a different form to synthesize a composite product. These can be either in a form of a long strip, whole bamboo, sections, and short bamboo fibers. The selection of their fiber kind depends upon the property to be imparted in the composite. Longer bamboo strips are used in making structural composite that is used in automobile roofings, shorter bamboo fibers are used in making of medium density fibreboard, ply bamboo are made up of bamboo vaneer and medium sized bamboo flake can be used for making of bamboo flake board [13]. Studies are going on to determine the feasibility of using bamboo for reinforcing concrete with flat symmetric structure decisions and smooth surface from a combination of bamboo, bamboo strips and wood veneer particles that play an important role as new material and is used for concrete formwork [14]. Although bamboo finds its wide application in various fields but their use in polymer matrix composites are very rare.

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CHAPTER 2
LITERATURE SURVEEY

This chapter deals with the consideration based on which the present work is being carried out. The purpose is to establish the relationship between varying size of short bamboo fiber in the composite and their mechanical behaviour.

In fiber reinforced polymer composite, the fiber used may be of different size [13]. Depending upon the application and the type of property to be imparted to the composite, size of fibers are accordingly determined. In fiber reinforced polymer composite, the reinforcing can be either of fibrous or can be non-fibrous. If the fiber used in the composite is derived from the natural resources like animals or plants, then the fiber is said to be natural fiber and the composite is said to be natural fiber reinforced polymer composite. Many a times, it does happen that the mechanical behaviour of a NFPCs do not gives a convincing result and have shown inconsistent values in many cases [15-17]. Lack of sufficient data for such fibers and their irregular characteristics are the prime reason behind this. On the other hand, there are several issues related to the natural fiber which wills to bring a full stop to the research going on in this field. But even though researchers have shown their benchmark contribution to this challenge and have become successful at many steps. The biggest challenge with the use of natural fiber is that these fibers are hydrophilic in nature i.e. they are moisture loving while many polymers are hydrophobic (moisture hating). Hence it has always been source of hindrance offered by natural fiber against its proper adherence with the matrix composite.

The mechanical behaviour of the NFPCs are mostly influenced by the large number of parameters like volume fraction of fibers, fibers length, fibers aspect ratio, fiber-matrix adhesion, fiber orientation, and stress transfer at the interface. Hence to improve the overall mechanical behaviour of the composites, the properties of matrix and fibers have to be improved first. Several investigations have been made on various natural fibers such as hemp, kenaf, flax, jute and bamboo to study the effect of these fibers on the mechanical and physical strength of composite materials [18-21]. Better the bonding at the interface between the fibers and the matrices better is the mechanical behaviour of the composite. Since the load can be easily transfer to the fibers by the matrix [22]. It has been reported by few investigators that the mechanical properties of the composites gets improved with increment in interfacial strength [23-25]. Bamboo finds its application in composite materials in several forms. These forms range from short bamboo fiber to long strips including the whole bamboo. Researchers have expanded their interest in the product development by using the usage of raw materials like bamboo fibre which is stronger as well as can be utilized in generating high end quality sustainable industrial products [26]. The impact strength of a composite when reinforced with a short bamboo fiber has been studied by several investigators for different fiber length and fiber content and optimum property has been reported [27].

Studies on characterised short sisal and coconut fibers composites as well as sisal fabric composites using compact tension specimens have been made. It was found that increasing fiber content increased fracture toughness of the composites [28]. Reinforcement of matrix with these short natural fibers increases the fracture toughness of the composites significantly [29]. Three different types of natural fibers coir, sugarcane bagasse and banana fibers were studied and it was found that all of these composites have their fracture toughness increased. Coir and sugarcane bagasse fibers reinforcement improved the fracture toughness by 15.7%, and 17.8% respectively. Polyester reinforced with short bamboo fibers ranging from 10 to 50, 30 to 50 and 30 to 60 vol% at increments of 10 vol% for bamboo fibers at 4, 7 and 10mm length respectively was studied. The increment in fiber content deteriorates the fracture toughness at 4mm of fiber length. Positive effect of fiber reinforcement was observed for 7 and 10mm fibers length. The optimum fiber content is found to be at 40 vol% for 7mm fiber and 50 vol% for 10mm fiber. The highest fracture toughness was achieved at 10 mm/ 50 vol% fiber reinforced composite, with 340 % of improvement compared to neat polyester [27]. The effect of short fiber on mechanical behaviour of composite has been studied by few investigators. The effect of chemical treatment on mechanical behaviour of banana fiber reinforced polyester composites has been studied and reported that the mechanical properties of different alkali treated banana fiber composites showed improved fiber matrix interactions [30]. Short sisal fiber reinforced with LDPE has been studied and it was shown that the tensile properties of the sisal-LDPE composites was enhanced [31]. Chemically treated natural fiber reinforced thermoplastic composites offered enhanced mechanical and physical properties under extreme conditions. Tensile properties such as tensile strength and tensile modulus of chemically treated short sisal fiber reinforced composites with different fiber loading has been studied [32]. Jute fibers are found to be very good in enhancing the fiber matrix adhesion and thus mechanical properties in jute fiber reinforced PP composites [33]. Impact behaviour of natural fiber reinforced polymer composites has been studied by few investigators [34-35]. Physical and mechanical properties of sisal fiber reinforced epoxy composites were reported by Bisanda and Ansell [36]. Yang et al. [37, 38] have studied mechanical properties and morphology of thermoplastic polymer composites filled with rice husk flour.

2.1 The knowledge gap

Through an extensive literature review, it has been observed that although the literature is rich in the study of mechanical behaviour of short natural fiber reinforced composites, however the precise and exact effect of short bamboo fiber reinforced polymers composites on mechanical properties is hardly been found.

2.2 Objective of the present research work

The knowledge gap in the present literature review has helped us to set the objectives of this research work which are pointy highlighted below:

a. Fabrication of a new class of epoxy based composites reinforced with short bamboo fibres.

b. Evaluation of mechanical properties such as flexural strength, impact strength, tensile strength and micro-hardness etc.

c. To study the influence of fiber lengths and fiber content on mechanical behaviour of short bamboo fiber reinforced epoxy based composites.

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CHAPTER 3
MATERIALS AND METHODS

This chapter deals with the materials that are used in the present study and the methods by which these materials are processed. The materials that are used in the present concern of study are:

1. Epoxy Resin
2. Short Bamboo Fiber
3. Hardener

3.1 Preparation of composites

Dry bamboo fibers were bought from the local market, Rourkela in the form of long strip with an average width of about 10mm. The fibers were then further left to be died for a week. After a week, the fibers of three different lengths i.e. 4mm, 7mm and 10mm and a width of approx. 3mm were cut manually. Epoxy Resin and the hardener (HY 951) were supplied by Ciba Geigy India Ltd. A wooden mould having a dimension of $200 \times 200 \times 40$ mm^3 was used for composite fabrication. Composites with three different wt.% (10wt.%, , 20wt.% and 30wt.% of fiber with length of 4mm, 7mm and 10mm was taken for the composite fabrication. The weighed epoxy and hardener is first manually stirred with a glass rod followed with an addition of weighed fiber. The fiber and epoxy resin is thoroughly stirred to make sure there is no air bubble trapped in the mixture. The mixture was then poured on a relieving sheet which was already placed in a mould. The mixture was uniformly distributed over the inner surface of the mould and then closed by another relieving sheet on its top. The mould was then closed and a constant dead load of 50 kg was put on the mould for the purpose of curing to enhance the mixture to take the desired shape of mould. The load was left for 24 hours and then released. The composite thus obtained was further allowed to be cured in air for another 24 hours. Figure 3.1 shows the fabricated short bamboo fiber reinforced composite. The various composition of short bamboo fiber reinforced epoxy based composites and their designation is presented below in Table 3.1

Figure 3.1 Short bamboo fiber reinforced epoxy based composite

Table 3.1 Composition and designation of fiber reinforced composites

Composites	Composition
C-1	Epoxy(90wt%)+Short bamboo fiber of length 4mm (10wt%)
C-2	Epoxy(80wt%)+Short bamboo fiber of length 4mm (20wt%)
C-3	Epoxy(70wt%)+Short bamboo fiber of length 4mm (30wt%)
C-4	Epoxy(90wt%)+Short bamboo fiber of length 7mm (10wt%)
C-5	Epoxy(80wt%)+Short bamboo fiber of length 7mm (20wt%)
C-6	Epoxy(70wt%)+Short bamboo fiber of length 7mm (30wt%)
C-7	Epoxy(90wt%)+Short bamboo fiber of length 10mm (10wt%)
C-8	Epoxy(80wt%)+Short bamboo fiber of length 10mm (20wt%)
C-9	Epoxy(70wt%)+Short bamboo fiber of length 10mm (30wt%)

3.2 Mechanical Testing of Composites

After the fabrication of bamboo reinforced epoxy based polymer composite, the sample of appropriate dimension were prepared to carry out various tests like tensile strength test, flexural strength test, micro hardness test and Impact test under ASTM standards. The tensile strength and flexural strength test were carried out using instrument TINIUS OLSEN H10KS (Figure 3.2). Both of these tests are carried out on flat specimen. A uniaxial load is applied to the specimen in both the direction of the specimen, finally leading to the failure of the specimen after ultimate stress. The ASTM standard test method for tensile properties of composites has the designation D 3039-76.

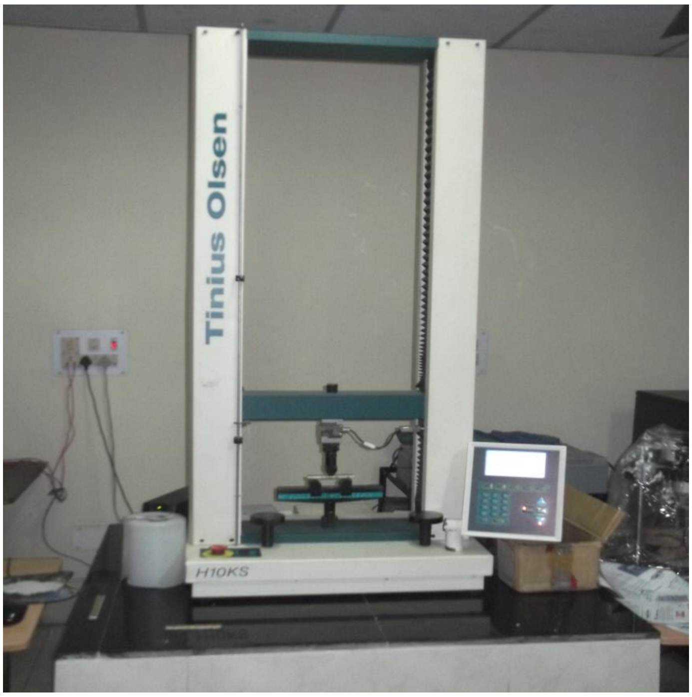

Figure 3.2 Experimental set up for tensile and flexural test

Micro hardness test was carried out by using the instrument named LECO hardness tester. The test is commonly known as Vicker's Micro hardness test. The specimen used in this case is also of flat shape. A diamond indenter of right pyramid shape with a square base and an angle of 136^0 between two opposite faces are forced into the material under a load, F kgf. After indentations (rhombus shape) produced by the indenter on the specimen, both the diagonals are measured and hardness value is thus calculated. The load considered in the present study is 0.1 kgf. The instrument is shown below in the Figure 3.3.

Figure 3.3 LECO Micro hardness tester

Impact strength of a material is defined as the property of a material by virtue of which the material opposes it fracture under stress applied at high speed. Impact strength of a polymer composite material is entirely related to its toughness as a whole. The instrument used for impact test in present study is Izod Impact Tester as shown in Figure 3.4.

Figure 3.4 Izod Impact tester

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CHAPTER 4

MECHANICAL PROPERTIES OF COMPOSITES: RESULT AND DISCUSSIONS

This section presents the various results obtained from various tests carried out in the present study. The mechanical behaviour of short bamboo fiber reinforced polymer composites with their various compositions are described here:

4.1 Mechanical characteristics of composites:

Mechanical properties of bamboo reinforced epoxy based composites such as tensile strength, flexural strength, impact strength and hardness number with their varying composition are tabulated below.

4.1.1 Effect of fiber parameters on tensile strength of composites

Tensile strength of a material is defined as the resistance offered by the material to get broken under tension. Effect of fiber loading and fiber length on tensile strength of composite is show below in Figure 4.1.

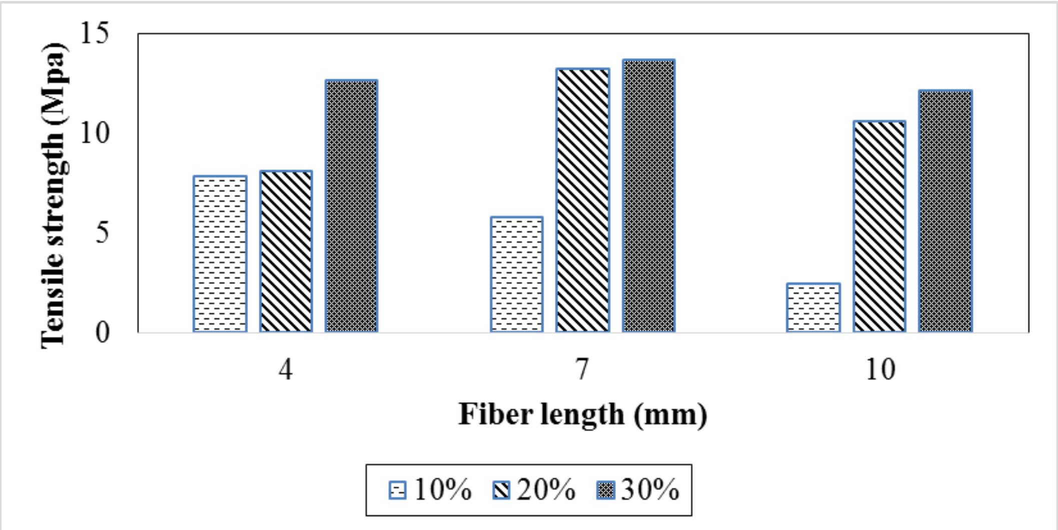

Figure 4.1 Effect of fiber parameters on tensile strength of composite

Tensile strength in this case varies with varying composition and it is found that the strength goes on increasing with increasing percentage of fiber in the composite for each length of fiber. The tensile properties measured in the present work are well compared with various earlier investigators [29], though the method of extraction of bamboo fiber is different. The tensile modulus indicates the relative stiffness of a material and can thus be obtained from stress strain diagram [39]. Optimum value of tensile strength for the composite is found to be at 30% fiber loading for each length of fiber. The highest value for tensile strength is for 30% fiber loading for a fiber length of 7 mm.

4.1.2 Effect of fiber parameters on flexural strength of composites

Flexural strength is defined as the ability of a composite by virtue of which it opposes the deformation likely to be imparted to it under the application of load. The effect of fiber loading and fiber length on flexural strength of composites is shown in Figure 4.2.

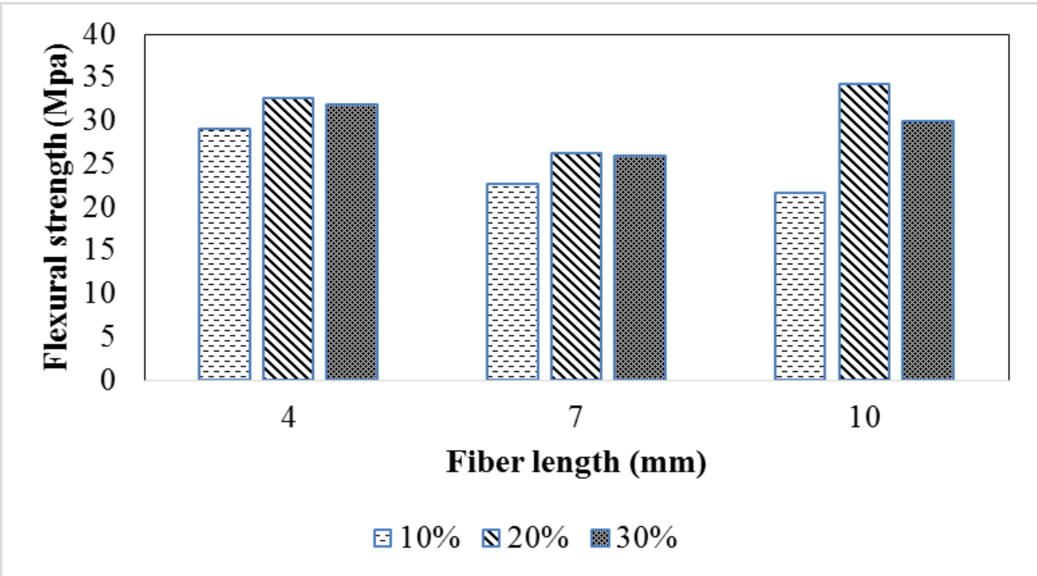

Figure 4.2 Effect of fiber parameters on flexural strength of composite

The test uses a flat specimen of rectangular cross section where the load is gradually applied with a speed of 1mm per minute until the specimen fails at the given load. The test is accompanied by three point bend test. Flexural strength for bamboo reinforced polymer composite increases with increasing fiber loading and then decreases. The same results comply for fiber length as well. The linearly increasing trend of flexural strength with increasing fiber contents suggests that the bonding between the fibers and the matrix is relatively good. The lower value of flexural strength at higher fiber content may be because of insufficient matrix in the composite which could not be able to transfer the load to the fibers. The effect of weight fraction of fibre on mean flexural strength for other fibre reinforced composites in comparison to bamboo composites are more. According to Ismail et al. [40] and Yao and Li [41], this decrease is attributed to the inability of the fiber, irregularly shaped, to support stresses transferred from the polymer matrix and poor interfacial bonding generates partially spaces between fiber and matrix material and as a result generates weak structure.

4.1.3 Effect of fiber parameters on impact strength of composites

Impact strength refers to a shock absorbing capacity of composite material. This is entirely related to a toughness of the composite material. The effect of fiber loading and fiber length on impact strength of composites is shown below in Figure 4.3.

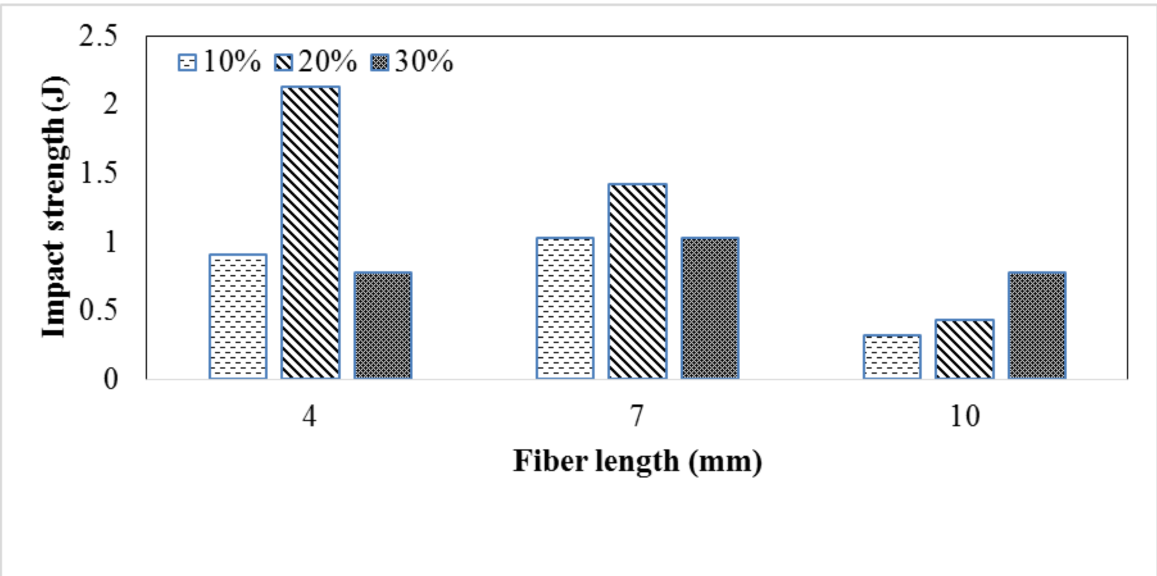

Figure 4.3 Effect of fiber parameters on impact strength of composites

The decrease in impact strength or smaller variation in strength may be due to induce microspaces between the fiber and matrix polymer, and as a result causes numerous micro-cracks when impact occurs, which induce crack propagation easily and decrease the impact strength of the composites [42, 43]. Generally the impact strength of composite materials increases with the increasing fiber content however the lower values of impact strength at higher composition of fiber may be because of improper adhesion between the matrix and the fibers. Higher content of fibers in composite requires higher matrix material but it is not likely to be so. Hence it is more likely that matrix is not able to transfer load to its fibers

4.1.4 Effect of fiber parameters on hardness of composite

Surface hardness of composite material is sometime a matter of concern when the composite material so produced is encountered for space application. For a given work, the composite material was subjected to Vicker's Hardness test and the following observations were made (Figure 4.4). From the figure, it is concluded that the hardness of a short bamboo fiber epoxy based composite increases with the increasing fiber content and fiber length up to a certain point and then it slowly drops down.

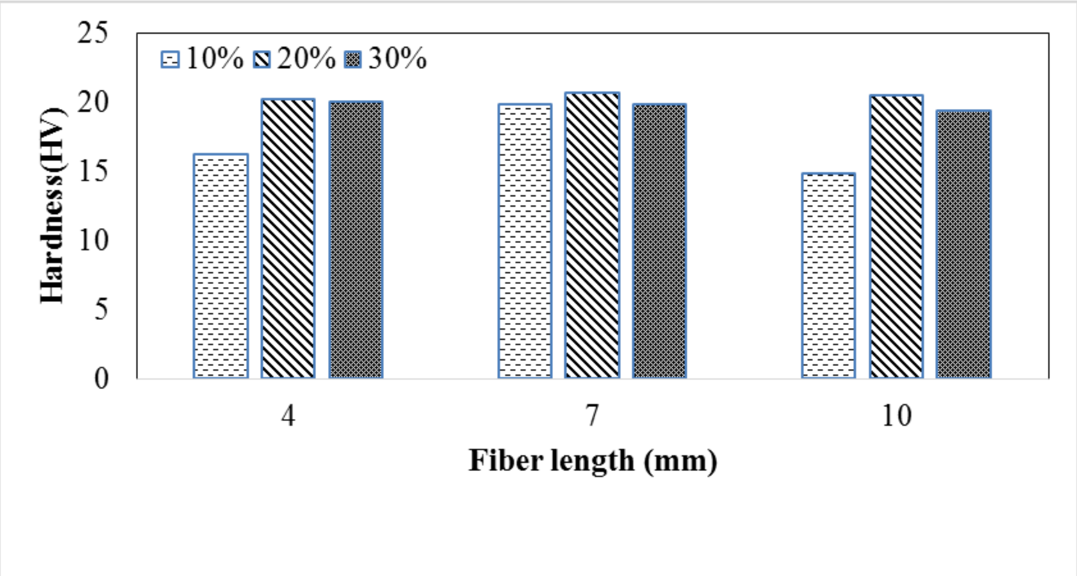

Figure 4.4 Effect of fiber parameters on hardness of composite

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CHAPTER 5
CONCLUSION

Short bamboo fiber reinforced epoxy based polymer composite was fabricated and its mechanical behaviour was studied. The conclusions drawn from this experimental investigation are as follows:

1. Epoxy based composite material reinforced with short bamboo fibers have been successfully fabricated.
2. It has been explored that the mechanical properties of the composites such as tensile strength, flexural strength, impact strength and hardness are highly influenced by the size of the fibers used.
3. Excess of fibers in composite materials deteriorate the mechanical properties of the composite because of lack of proper bonding between the matrix and fiber around their interface. This causes the disruption in transfer of load to the bonding fibers. Lower values of impact strength and flexural strength at higher composition of bamboo fibers may be because of this reason.
4. The present study reveals that impact strength, tensile strength and flexural strength increases with increasing content of fiber in composite materials.

5.1 Scope for future work

This area of research can be extended to other varying size of bamboo fibers which may be in form of flake, whole bamboo, sections, strips etc. in order to achieve the desired mechanical properties in composite materials. Presently, epoxy, reinforced with bamboo and hemp with saw dust as a filler material is hot topic of research and is used to fabricate an eco-friendly helmet which can be a substitute for synthetic helmets. This fabrication includes compression molding technique. Further research in the field of bamboo composites can be extended to the fabrication of eco-friendly tyres by converting the bamboo fibers into its carbon black and then treating it with the thermoplastic resin [13].

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